BELL Helicopter CORPORATION

POST OFFICE BOX 482 • FORT WORTH 1 TEXAS

# TECHNICAL DATA

BY Lowell E. Wilkerson DATE December 15, 1958
Lowell E. Wilkerson

CHECKED DATE

APPROVED DATE

APPROVED W. G. Matheny DATE December 15, 1958
W. G. Matheny

MODEL NO. OF PAGES

REPORT NO. D228-420-004 DATE 12-15-58

TITLE

A STUDY TO DETERMINE HOW WELL RATE CAN BE DISCRIMINATED AND CONTROLLED

PREPARED UNDER CONTRACT Nonr-1670(00)

REPORT SEQUENCE NUMBER

PERIOD COVERED

E4-501 FW Rev 157

# A STUDY TO DETERMINE HOW WELL RATE CAN BE DISCRIMINATED AND CONTROLLED

Lowell E. Wilkerson
W. G. Matheny

December 1958

OFFICE OF NAVAL RESEARCH
Contract Nonr 1670(00)

## FOREWORD

This report constitutes an effort to determine how well people judge and control rates. It concludes with a best way to encode rate information. Special acknowledgment is made to Janet Tucker for the laborious task of reducing the Sanborn tapes and to George Fox for assisting in the analysis of the data. This report was prepared at Bell Helicopter Corporation under Contract Nonr-1670(00).

# ABSTRACT

The Army-Navy Instrumentation Program has spotlighted the need for more information on the judgment and control of rates. The embryo helicopter pilot must learn to judge and control several rates of movement before he is able to accomplish the one task of hovering. Little is known of how well rates can be judged and controlled when encoding rate through the use of some symbol or index. Assuming they are judged and controlled within acceptable limits, how should this information be encoded?

Sixteen flight naive and eight flight experienced people were used as subjects. They were presented two symbols, a line and a circle which either expanded or contracted. Each subject was given eight trials in each of the four conditions. The analysis of the data revealed that each of the groups tested made smaller final rate and final position errors when using the contracting circle.

# A STUDY TO DETERMINE HOW WELL RATE CAN BE DISCRIMINATED AND CONTROLLED

## INTRODUCTION

A basic assumption of the Army-Navy Instrumentation Program is that the operator of a flight vehicle needs an artificial picture with the same identity relationships as that created between himself and his observed world when flying "on instruments". A problem encountered when encoding an analogue of this observed world is to determine the proper rate of movement for each of the symbols used and the proper rates of movement when they are combined. The helicopter pilot has had to learn to judge and control several rates of movement before becoming qualified in the helicopter.

Although pilots have been judging rates for a long time, little is known of how well they can judge and control them. This is especially true when we want to encode rate through the use of some symbol or index.

A survey of the literature reveals little information bearing directly on this problem. In 1928, M. Pelligrini and M. Ponzo[1] studied individual and interindividual variations in judging the speed of an automobile in motion. They reported the errors in judging speed were greater while slowing down or speeding up than during constant motion. While slowing down the speed was underestimated and when speeding up the speeds were overestimated.

Other variables that affect rate judgment at the threshold values are brightness, size of object, background detail, exposure time, monocular or binocular vision, to name a few. Psychologists in the past have been more concerned with these variables that affect the threshold values than with how well a person judges absolute values of rate.

Aubert, as reported by Dimmick & Karl[2] in 1886, found when the field was restricted to a drum seen through an opening in an otherwise uniform black field that the limen was increased tenfold. Repeating the same experiment with a point of light in a lightless field, he found perception of motion became highly unstable. The presence of a second stationary line did not materially alter the results. B. Bourdon, also reported by Dimmick & Karl[2], found that motion is perceptible in a totally restricted field, but that it requires a considerable amplitude. Dimmick and Karl[2] in 1930, reporting on the effect of exposure time on the lower limen, found that as exposure time increases the lower limen for perception of visible motion decreases. Graham, et al, as reported by Zeger, R. T.[3], found that the factors influencing monocular movement parallax were: (1) the movement parallax threshold is lower when the eye follows the stimulus, (2) discrimination of the threshold of depth difference is determined by distance cues other than difference in object size, (3) an increase in a rate of basic movement results in an increase in the threshold differential angular velocity, (4) movement parallax threshold decreases as intensity of illumination increases and finally reaches a limiting value at high intensity, and (5) threshold differential angular velocity is about twice as great along the vertical axis as along the horizontal.

In 1945 Adams, Ellson and Gray[4] reported on, "A Study of Rate Tracking by Gunners on the B-29 Pedestal Sight". In this study trained and untrained gunners used the B-29 pedestal sight to do rate tracking of a target moving either 2 or 6 degrees per second in azimuth. Adequacy of performance was determined by examining the output of the automatic lead computers. It was found that the mean probable deviations in computer output were 2 or 3 times as great with gunner's rate tracking as with mechanical rate tracking, which may mean if accuracy of tracking is the prime criteria it should be accomplished by mechanical or electronic means. However, a look at the total mission must be undertaken before this decision is made. Answers to such questions as: When is high accuracy needed? How much is the probability of success of the total mission increased? What reliability of the man-machine system is required? These and other questions must be answered before an intelligent division of the total task can be attempted.

Assuming that the helicopter will carry a pilot and he will be required to take off and land, the kind of information best used by the pilot becomes a critical problem. Is it better to present position-type information, rate-type information or some third- or fourth-order derivative of position information? All present-day instruments, with the exception of the rate-of-turn needle and rate-of-climb instrument, give position-type information. Rate information can be derived from some of these instruments by integrating position with respect to time. Third- and fourth-order derivatives of position are present in today's instruments, but their utilization by the human operator is highly questionable. If the machine is allowed to maneuver in a normal manner, presenting third or fourth derivative information is probably useless because of the duration of the period they are present. Under normal circumstances position can be maintained for a reasonably long period of time. The same can be said about rates. However, the duration of an acceleration or a rate of onset is a considerably shorter period of time. In fact, they are of such a short duration it is highly improbable that a pilot could read and act upon more than one or two parameters of information presented in their primary form unless, of course, a delay term or lead term could be introduced into the signal which would be lagging or leading the actual system output. This type of information is unusable by the pilot in a normal situation, and fatal in an emergency. If the foregoing logic holds, then the most fruitful of the position derivatives to study is rate. This experiment was designed to determine how well a person could control and discriminate rates and rates of change of rates (deceleration) given certain ways of encoding the information. Two different symbols were used, a line and a circle. They could either be expanded or contracted to show a rate of change, to test, for example, the influence of an expanding circle as compared with one which contracts upon the discrimination and control of rates.

## THE EXPERIMENTAL DESIGN

A Latin square design was used. Each of the subjects performed the task eight successive times in each of the four experimental conditions using four control sensitivities. Since the same task was performed in each of the experimental conditions, by all subjects, it was to be expected that there would be improvement in the performance of the task by each subject during his testing series.

To balance out any such practice effects, interference effects, transfer from one condition to another, etc., each of four subjects were tested in the four conditions in a different serial order as shown in Figure 1.

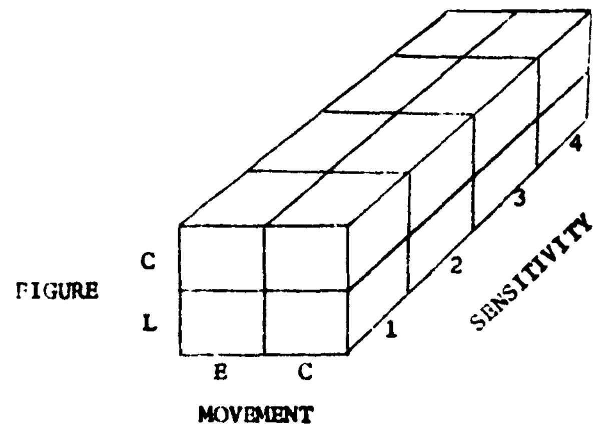
The same balanced design was used to limit the usefulness of the control as a cue in making judgment about zero rates and zero positions as shown in Figure 2.

The last four control sensitivities were the reverse of the first four. The second subject received the control sensitivities in reverse order to subject number one. Each group of eight subjects received the control sensitivities in a different columnar order, i.e., subject 3 started with sensitivity 4 in his first condition, subject 4 with sensitivity 2, etc.

EXPERIMENTAL APPARATUS

A standard 5" cathode ray tube was used as the display media in this experiment. The front of the tube was modified for a quick change of the reference index. The hood was slotted so that the plexiglas with inscribed indices could be placed next to the tube face. The indices were concentric circles on yellow #2048 plexiglas. The sweeping circuit of the CRT was modified with a switching circuit to allow the target symbol and moving symbol to appear on the scope simultaneously. This procedure nullified the drift inherent in the CRT. The subject's control was a six-inch diameter wheel mounted vertically on the right arm of the subject's seat with the axis of rotation perpendicular to the arm.

EXPERIMENTAL DESIGN




C = Circle
L = Line
E = Expand
C = Contract

REPLICATION OF CONDITIONS

| SUBJECTS | ORDER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| * 1 | 1* | 4 | 2 | 3 |
| 2 | 4 | 3 | 1 | 2 |
| 3 | 2 | 1 | 3 | 4 |
| 4 | 3 | 2 | 4 | 1 |
| 5 | 4 | 3 | 1 | 2 |
| 6 | 2 | 1 | 3 | 4 |
| 7 | 3 | 2 | 4 | 1 |
| 8 | 1 | 4 | 2 | 3 |
| 9 | 2 | 1 | 3 | 4 |
| 10 | 3 | 2 | 4 | 1 |
| 11 | 1 | 4 | 2 | 3 |
| 12 | 4 | 3 | 1 | 2 |
| 13 | 3 | 2 | 4 | 1 |
| 14 | 1 | 4 | 2 | 3 |
| 15 | 4 | 3 | 1 | 2 |
| 16 | 2 | 1 | 3 | 4 |

* Numbers in cells refer to condition under which trial was run as follows:

1 = Line Expanding (LE)
2 = Line Contracting (LC)
3 = Circle Expanding (CE)
4 = Circle Contracting (CC)

FOR EXAMPLE, Subject #1 received the conditions in the following order:

| SUBJECT | CONDITION |
|---|---|
| 1 | 1 (LE) |
| | 4 (CC) |
| | 2 (LC) |
| | 3 (CE) |

FIGURE 1.

[illegible]

## ORDER OF PRESENTING CONTROL SENSITIVITIES

| | CONDITION | TRIALS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Subject 1 | 1 | 1* | 4 | 2 | 3 | 3 | 2 | 4 | 1 |
| | 4 | 4 | 3 | 1 | 2 | 2 | 1 | 3 | 4 |
| | 2 | 2 | 1 | 3 | 4 | 4 | 3 | 1 | 2 |
| | 3 | 3 | 2 | 4 | 1 | 1 | 4 | 2 | 3 |
| Subject 2 | 4 | 3 | 2 | 4 | 1 | 1 | 4 | 2 | 3 |
| | 3 | 2 | 1 | 3 | 4 | 4 | 3 | 1 | 2 |
| | 1 | 4 | 3 | 1 | 2 | 2 | 1 | 3 | 4 |
| | 2 | 1 | 4 | 2 | 3 | 3 | 2 | 4 | 1 |

Replicated for 16 subjects

* Sensitivity

EXPERIMENTAL APPARATUS -- Contd.)

The edge of the wheel was one and one-half inches wide. For each trial the displacement of the control for a given rate was changed, as indicated by the experimental design. After each trial the control was set on zero rate by aligning a set of reference marks. The control was capable of a positive or a negative input to the drive mechanism which controlled the increasing or decreasing size of the symbol. Two Sanborn recorders were used to record position and rate. The position tape was calibrated so that a discrete line on the tape corresponded with a discrete position of the display and the rate tape was calibrated to accommodate the maximum rate of change of the display. Each tape was coded simultaneously at the beginning and end of each trial and when the subject pushed the event marker indicating that he judged himself to be at a zero rate at the reference circle.

The experimenter's control station had the appropriate controls to change from a line to a circle and from expanding to a contracting condition. A referent change was made by simply lifting one face out of the slot and inserting another.

SUBJECTS

A flight experienced group and a flight naive group were used in the experiment. The eight subjects in the experienced group were members of the Bell Helicopter flight test staff. The sixteen volunteer naive subjects work in the Engineering Department. All had normal vision, as measured by the Snellen Eye Chart. The ages of the naive group ranged from 19-26 with an $\bar{X}$ of 24.6. The pilot group age averaged 37 with a range of 33-47.

The subjects in the naive group had never flown a helicopter, airplane or simulator, nor had they participated in an experiment of a psycophysical nature.

PROCEDURE

Before an experimental session began the subject was read a carefully prepared set of instructions (see Appendix). After all questions pertaining to the task were answered, the subject was given two practice trials on each condition with different control sensitivities.

The subjects performed each of the experimental conditions using four different control sensitivities. In each condition he was required to attain a rate of movement by the time a discrete position on the scope face was reached, to hold this rate of movement for another discrete distance, then to decrease this rate at a constantly changing rate to reach a zero rate at the zero position. This was accomplished for both the circle and the line. After each trial the control sensitivity was changed before the next trial began. An opportunity to overshoot or undershoot was provided in the design of the equipment. The subjects were told at the start of the experimental period their primary task was to attempt to have a zero rate at the zero position. An event marker was controlled by the subject. When the moving symbol was judged to be stopped and coincident with the target symbol, the subject pushed a button actuating an event marker which marked both the rate and position tapes. This signified the end of a trial and the equipment was then readied for the next trial.

The subjects were allowed to attain their own rate of movement of the symbols. Each trial was started with a forward motion of the control regardless of the direction of movement of the symbol.

## STATISTICAL ANALYSIS

## RATE EXPERIMENT I

### MEASUREMENTS

Data was recorded on two Sanborn recorders. One Sanborn recorded position, the other rate. The position tape produced one set of data called final position. These were the deviations about the final position index. The rate tape provided four other measures for analysis. These were the measurements of final rate, deviations about a constant deceleration or performance, time of descent, and total time.

### ANALYSIS METHODS

The parametric analysis of variance was used in all those cases where the underlying assumptions could be met. When tests for homogeneity and normality showed the inadvisability of using the parametric test, Dr. K. V. Wilson's Distribution-Free Test of Analysis of Variance Hypothesis[5] was used. As shown in Table 1, there was no significant differences in the main effects of figure when using the line or the circle. However, further analysis shows that there was significant interactions in the conditions tested.

Final Position: The deviations from final position were signed according to the following method. A subject indicating zero position before reaching the zero point was given a positive deviation, accordingly if the figure had passed through the zero position before the indication

TABLE 1.

SUMMARY

| | PERFORMANCE | | TOTAL TIME | | TIME OF DESCENT | | FINAL RATE | | FINAL POSITION | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $\bar{x}$ | $\sigma$ | $\bar{x}$ | $\sigma$ | $\bar{x}$ | $\sigma$ | $\bar{x}$ | $\sigma$ | $\bar{x}$ | $\sigma$ |
| **FIGURE:** | | | | | | | | | | |
| Circle | 8.38 | 2.77 | 85.23 | * 22.56 | 50.42 | * 9.76 | 2.52 | 1.25 | .70 | 2.47 |
| Line | 8.97 | 2.69 | 61.90 | 14.20 | 34.58 | 8.62 | 2.73 | 2.05 | 1.51 | 2.45 |
| **MOVEMENT:** | | | | | | | | | | |
| Contracting | 8.29 | 2.85 | 74.75 | 21.97 | 45.45 | 12.39 | 2.51 | 1.74 | .95 | 2.70 |
| Expanding | 9.06 | 2.81 | 72.38 | 15.20 | 39.55 | 6.86 | 2.73 | 1.22 | 1.26 | 3.30 |
| **SENSITIVITY:** | * | | | * | | | | | | |
| 1 | 12.29 | 3.49 | 58.47 | 16.98 | 38.34 | 11.27 | 1.98 | .97 | 1.12 | 2.52 |
| 2 | 8.52 | 3.18 | 69.43 | 15.70 | 40.55 | 7.43 | 3.17 | 1.22 | 1.11 | 2.16 |
| 3 | 7.45 | 2.79 | 76.11 | 18.36 | 42.86 | 9.09 | 2.98 | 1.24 | 1.02 | 2.37 |
| 4 | 6.44 | 1.97 | 90.25 | 21.11 | 48.27 | 9.39 | 2.34 | 1.81 | 1.28 | 3.17 |
| **FIGURE & MOVEMENT:** □ | * | | | | | | | * | | |
| CC | 9.21 | 3.24 | | | | | 1.62 | 1.26 | .35 | 2.59 |
| CE | 7.55 | 2.84 | | | | | 3.41 | 1.88 | 1.07 | 3.52 |
| LC | 7.38 | 3.52 | | | | | 3.39 | 3.36 | 1.57 | 2.67 |
| LE | 10.56 | 3.20 | | | | | 2.06 | 1.21 | 1.46 | 3.22 |

* Significant at .01

□ Only significant interactions shown

TABLE 1.

SUMMARY

| | FINAL RATE | | FINAL POSITION | | PERFORMANCE | | TOTAL TIME | | TIME OF DESCENT | | FINAL RATE | | FINAL POSITION | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\bar{x}$ | $\sigma$ | $\bar{x}$ | $\sigma$ | $\bar{x}$ | $\sigma$ | $\bar{x}$ | $\sigma$ | $\bar{x}$ | $\sigma$ | $\bar{x}$ | $\sigma$ | $\bar{x}$ | $\sigma$ |
| 6 | 2.52 | 1.25 | .70 | 2.47 | 11.83 | 7.26 | 87.13 | 39.88 | 54.97 | 24.34 | 2.20 | 1.25 | .70 | 1.10 |
| 2 | 2.73 | 2.05 | 1.51 | 2.45 | 13.64 | 8.85 | 78.80 | 33.12 | 51.96 | 26.57 | 1.76 | 1.79 | .49 | 1.36 |
| 9 | 2.51 | 1.74 | .95 | 2.70 | 11.51 | * 7.39 | 90.29 | * 41.22 | 61.26 | * 31.54 | 1.91 | 1.75 | .32 | * 1.33 |
| 6 | 2.73 | 1.22 | 1.26 | 3.30 | 13.96 | 8.67 | 75.63 | 30.86 | 45.66 | 17.95 | 2.07 | 1.42 | .86 | 1.82 |
| 7 | 1.98 | .97 | 1.12 | 2.52 | 18.13 | * 8.81 | 70.11 | * 29.41 | 50.69 | 23.75 | 1.32 | 1.56 | .34 | .96 |
| 3 | 3.17 | 1.22 | 1.11 | 2.16 | 12.59 | 7.29 | 78.82 | 38.07 | 51.78 | 27.57 | 1.89 | 1.53 | .43 | 1.17 |
| 9 | 2.98 | 1.24 | 1.02 | 2.37 | 10.53 | 6.57 | 86.34 | 39.48 | 53.58 | 26.63 | 2.49 | 1.58 | .72 | 1.29 |
| 9 | 2.34 | 1.81 | 1.28 | 3.17 | 9.67 | 6.15 | 96.58 | 38.59 | 57.81 | 23.44 | 2.16 | 1.78 | .87 | 1.26 |
| | 1.62 | * 1.26 | .35 | 2.59 | 11.88 | * 6.79 | | | | | 1.48 | * 1.14 | .01 | 1.68 |
| | 3.41 | 1.88 | 1.07 | 3.52 | 11.77 | 6.99 | | | | | 2.99 | 1.75 | .98 | 2.47 |
| | 3.39 | 3.36 | 1.57 | 2.67 | 11.14 | 7.93 | | | | | 2.34 | 2.86 | .65 | 2.12 |
| | 2.06 | 1.21 | 1.46 | 3.22 | 16.14 | 9.02 | | | | | 1.16 | 1.37 | .75 | 2.55 |

shown

was made the deviation was considered as negative. This method was used on all experimental conditions. Due to the negative numbers involved a value of +12 was added to all deviations, pilot and non-pilot, before any statistical procedures were carried out.

In both pilot and non-pilot groups the distribution of deviations was found to be close enough to normal to proceed with a parametric analysis of variance. Investigation into the distribution of variance proved the data to be homogeneous in nature.

Final Rate: Positive and negative signs were given on final rate deviations in the same manner as the case of final position. A value of +25 was added to all deviations to eliminate minus signs before any statistical procedures were initiated.

The scores of the non-pilot group were found to be normally distributed and to show homogeneity of variance; therefore the analysis of variance method of analysis was used. The analysis was performed with raw, untransformed data. The readings from the pilot group were found to lack normality of distribution and homogeneity of variance. Due to the failure of the data to satisfy the two basic assumptions required for the analysis of variance a nonparametric analysis was performed.

Performance: To determine how well the subjects could judge and execute a constant decreasing rate to a zero rate and a zero position, a straight line was drawn from the point at which a decrease in rate was evidenced to zero rate at the point the subject indicated he was at a zero rate and a zero position. This line was then divided into twenty equal units. These different points were then read as deviations from this inscribed line. A "V" score was obtained from these twenty deviation scores using the formula $V = \sqrt{\frac{\Sigma x^2}{N}}$. $V = \sqrt{\frac{\Sigma(\text{std} - X)^2}{N}}$, but the standard equals 0. Therefore, $V = \sqrt{\frac{\Sigma x^2}{N}}$. In analysis the V-score was considered as raw data.

Due to the fact that V-scores are not distributed normally, the data were transformed using logarithms to the base ten. Normality thus restored, the analysis of variance was performed on pilot and non-pilot performance data.

Time of Descent: Time measures were computed from the tapes for the time spent under decreasing rate. In the case of the non-pilot group the data were homogeneous but lacked normality of distribution. A log transformation converted the shape of the curve satisfactorily and an analysis of variance was performed.

On pilot data, the data failed to meet a test for homogeneity of variance as well as showing a non-normal distribution; therefore, a non-parametric analysis was used.

Total Time: Total time was measured from the point of the first control movement to the point where the indication of zero rate and position was made. As in the case of descent time a log transformation was necessary on the non-pilot data to achieve the requirement of normality. A nonparametric analysis was used on pilot group data due to lack of homogeneity and normality.

## RESULTS

This experiment was designed to minimize the problem of the subject's utilizing control displacement as a cue in judging final position. As shown in Table 1, there were no significant interactions between figure, movement and sensitivity. Only those interactions that were significant are shown on this table. Using time as a criteria of performance there is a significant difference between the sensitivities when total time is used as a measure of performance; however, using time of descent as a performance measure no significant difference is evidenced.

Total time was divided into three separate times: time to attain a constant rate, time at a constant rate, and time of descent. Assuming that time of descent is the best measure of the time variable in making judgments of how well a subject performed, the control did not aid in the judgment of final rate or position. Therefore, the subjects were forced to receive all their rate and position information through the visual senses. The accuracy with which the subjects were able to judge final position of the symbols was determined by their ability to differentiate and discriminate the moving symbol to be coincident with the target symbol.

The first question to be answered was, how well can the human operator judge and control rates? An analysis shows that rates can be discriminated and controlled consistently and accurately within the limits set forth in the experimental design. Performance in this experiment means how well the subjects could discriminate and control a changing velocity, which would produce a constant glide angle to a desired point. Deviations about this desired path is one measure of how well the subjects were able to interpret and control the displays presented.

An analysis of the performance scores of the pilot group showed no statistical significance of the main order effects of figure or movement. However, as the control sensitivity was decreased a corresponding decrease in the error scores was significant. The test of the interactions showed only one significant interaction, that was the one of figure by movement. The pilot group's performance scores were significantly smaller when using the contracting line.

The total time measure for the pilot group, when subjected to an analysis, showed that they used significantly less time when operating with the line. This time measure showed no difference as to the direction of movement of the symbols. However, as the sensitivity of the control was changed there was a significant difference in the amount of time used. The more sensitive the control the less time consumed. There were no significant interactions of the time measure. The above results apply also to the time of descent measure, with one exception. The changing of the control sensitivity did not significantly affect the time of descent.

Another measure of how well the subjects could discriminate and control rate is the accuracy with which they were able to stop the movement of the symbol on the target. The actual amount of displacement of the controlled symbol indicated that, in his judgment, the two were coincident yielded two measures. These were <u>final rate</u>, or rate of movement of the controlled member when it was judged to be at zero position, and <u>final position</u>, or amount of actual displacement from zero when displacement was judged to be zero. An analysis of these scores gives an excellent indication of the accuracy with which this type of rate information was discriminated and controlled.

The final rate measure showed no significance for figure, movement or sensitivity. The interaction of figure by movement showed that the pilot group had significantly smaller errors with the contracting circle. The final position measure showed no statistical significance for the main variables of figure, movement, or sensitivity. There were no differences shown in the interactions.

The analysis of the scores of the non-pilot group produced essentially the same results as the pilot group. The performance scores indicated no differences between the two symbols used. They did show that the direction of movement was significant, the contracting condition producing the smallest errors as well as the smallest amount of variability. Again the performance scores showed a significant difference as the sensitivity was changed, the errors getting smaller with less variability as the control sensitivity decreased. The figure by movement interaction resulted in a statistical difference; however, the three conditions of contracting circle, expanding circle, and contracting line being different than the expanding line, but a "t" test between the combinations of the three conditions produced no difference. The error variability was smallest with the contracting circle.

An analysis of the total time scores of the non-pilot group showed no differences in the two symbols. The movement and control sensitivity variable did show statistical differences. An expanding condition resulted in a significant saving in time, as did increasing the sensitivity of the control.

Time of descent scores produced about the same results as the total time score with one exception. Changing the control sensitivity did not significantly affect the time of descent.

The final rate scores showed no significant differences in the symbols used, the direction of movement, or the sensitivities. A statistical difference was demonstrated on the interaction of figure by movement. The expanding line condition resulted in the smallest average error; however, the contracting circle produced the least amount of variability. A "t" test showed no difference between the two conditions.

Analysis of the final position scores indicated no difference between the circle or line. A statistical significance was shown for the direction of movement. The contracting condition produced the smallest final position error.

Control sensitivity did not significantly affect final position. The figure by movement interaction showed a difference between the conditions tested. The contracting circle produced the smallest errors and the least amount of variability.

## SUMMARY

In summary, if performance, as previously defined, is used as the criteria the results of these data indicated the circle to be the preferred symbol. The movement of the symbol should be contracting and the less sensitive the control the better the performance. However, if time is the prime criteria, less time was used with the line and the expanding condition. The more sensitive the control produced the shortest times. Whereas, using the measures of final rate and final position as the prime criteria, the contracting circle produced the smallest errors with the least amount of variability.

## DISCUSSION

The results of this study show that pilots and non-pilots can control rates in a consistent manner when operating within the limits set forth in this experiment. It also showed that final position judgments were consistently good with little variability.

The question of what symbol to use when encoding rate information appears to be of little importance to either group. They both performed equally well using the line or the circle. The non-pilot group did perform somewhat better using the circle; however, this difference was significant at only the .05 level of confidence.

Movement of the symbol did not significantly affect the performance of the pilot group, while the non-pilot group performed significantly better with contracting condition. The performance and accuracy of the pilot group, as shown in Table 3, was better when using the circle and the contracting movement. A check of Table 1 shows the non-pilot group also performed better with the contracting movement. However, as to which symbol to use in performance and accuracy, they differ from the pilot group. Their performance errors were smaller with the circle, but a greater degree of accuracy of final position and final rate was demonstrated with the line. As indicated, none of these were significant. When considering displaying this type of rate information the question arises as to where in the flight program a new type display should be introduced and/or can it be used operationally? With this as a goal it is interesting to note the small differences between the pilot and the non-pilot groups. In general, the data shows them to be in consistent agreement as to the symbol to use and the direction of movement it should have.

To determine how well rates can be judged and controlled in a practical situation the landing mode of a helicopter mission lends itself nicely. The helicopter pilot in making an approach for landing at some point on the descent begins decreasing airspeed, ground speed, rate of descent and rate of closure to the touch-down point to reach a position of hover over the landing spot, then to slowly descend to zero position with a minimum amount of rate. The primary purpose of the pilot is to execute the landing without damaging the helicopter. His actual performance and time consumed to accomplish this is secondary. Therefore, final position and final rate were used as primary parameters in determining how well the subjects were able to judge and control rates.

The total travel of the symbols across the CRT was 1.625 inches. This was represented on the Sanborn tape as four centimeters of excursion.

Each millimeter was divided into four equal parts; therefore, 160 units equalled 1.625 inches of travel. One unit of position represents .01 inches on the CRT. Assuming the rate to be constant at the time the naive subjects indicated zero rate and zero position, their mean rate over all conditions was .02 inches per second referenced to the scope face. Their mean position error over all conditions was .006 inch. The experienced subjects' mean rate at the time they indicated a zero rate and zero position was .026 inches per second with a mean position error of .011 inches referenced to the scope face. If it is assumed that rate and position can be discriminated and controlled within the same limits on a contact analogue, what range of values can these mean units of error represent?

One unit of rate can be set to equal .805 feet per second. One unit of position can be arbitrarily set at 1 foot. Using these figures to determine how well subjects can control rate and judge position, we find the pilot group on the average was able to judge position within 13.3 inches, with a mean rate of 2.11 feet per second from an altitude of 160 feet. The non-pilot group judged position within 7.08 inches, with a mean rate of 1.60 feet per second. If in both cases the subjects held the rate constant at this point until contact with the ground was made, the pilot group's average force upon contact with the ground would be 1.92 G's, and the non-pilot group would contact the ground with a force of 1.76 G's. A force of 2.4 G's is needed to produce a yield of the cross tubes on the skid gear, and a force of 3.5 G's for ultimate yield. The yield is defined as a force great enough to produce a permanent set greater than .2 of one percent[6]. An ultimate yield is a force great enough to cause replacement, but does not mean that the structure failed. If we let the maximum distance that the symbol traveled represent 80 feet of altitude, the subjects then could judge their position within 4.2 inches. A decrease in the amount of altitude the symbol must represent makes for a corresponding decrease in the mean error. A 20-foot scale would produce a mean error of 1 inch, whereas a scale of 1,000 feet would produce a mean error of 5 feet. The same holds true for the rate. A decrease in the range of rates the symbol must represent makes for a corresponding decrease in the mean error. Sixty-one percent of the non-pilots and 52% of the pilot group's final rate was in error by only 2 units or less, as shown in Figures 4 and 6 in the Appendix.

An examination of Figures 3 through 11 gives information as to how position information, rate information, or rate plus position information should be encoded. The percent of total errors is plotted along the ordinate and arbitrary units of error along the abscissa. The prime criteria, of course, is the accuracy required. If the required accuracy for position is two units or less, Figure 3 shows that inexperienced people will do better with a contracting circle; however, if the required accuracy is 1 unit or less they will perform equally well with the contracting circle or contracting line. The experienced person will also do better with the contracting circle for an accuracy of two units or less, but with a required accuracy of one unit or less they will do better with a contracting line, as shown in Figure 7. Figure 9 is a plot of the per cent of total errors for both groups and shows that the contracting circle should be used for a required accuracy of two units or less.

Assuming a requirement to encode both rate and position with one symbol, Figure 11 shows that for both experienced and inexperienced people the contracting circle is best throughout the range of accuracies shown.

Further experimentation is needed to determine how knowledge of results, encoding, etc., affects rate and position judgments. Also, what problems are encountered when combining a decreasing circle symbol with other symbols which present information about different parameters.

Figure 3

A DETERMINATION OF THE DISCRIMINATION & CONTROL OF RATE INFORMATION

POSITION
NON-PILOTS

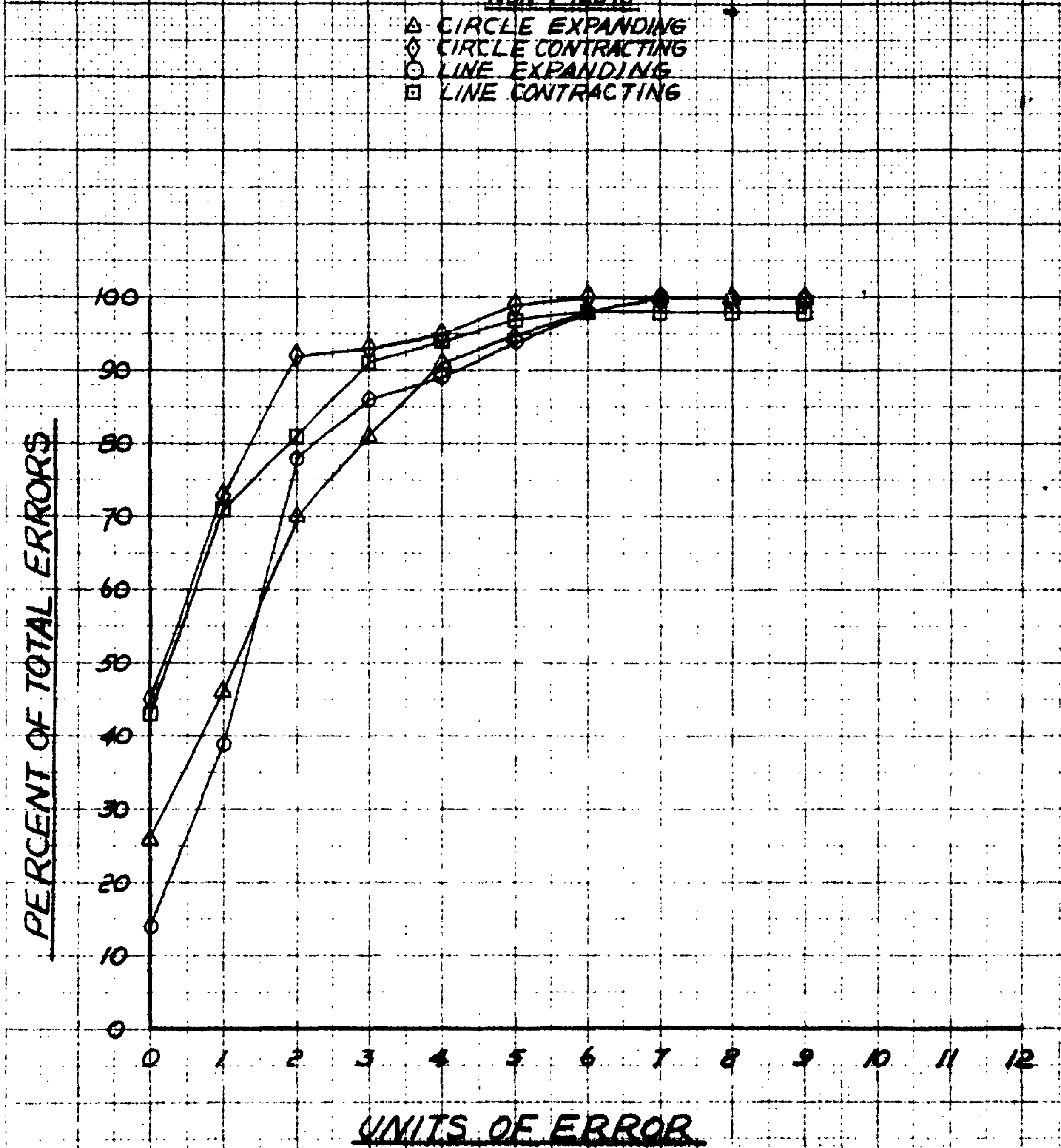


Figure 4

A DETERMINATION OF THE DISCRIMINATION & CONTROL OF RATE INFORMATION

RATE

NON-PILOTS

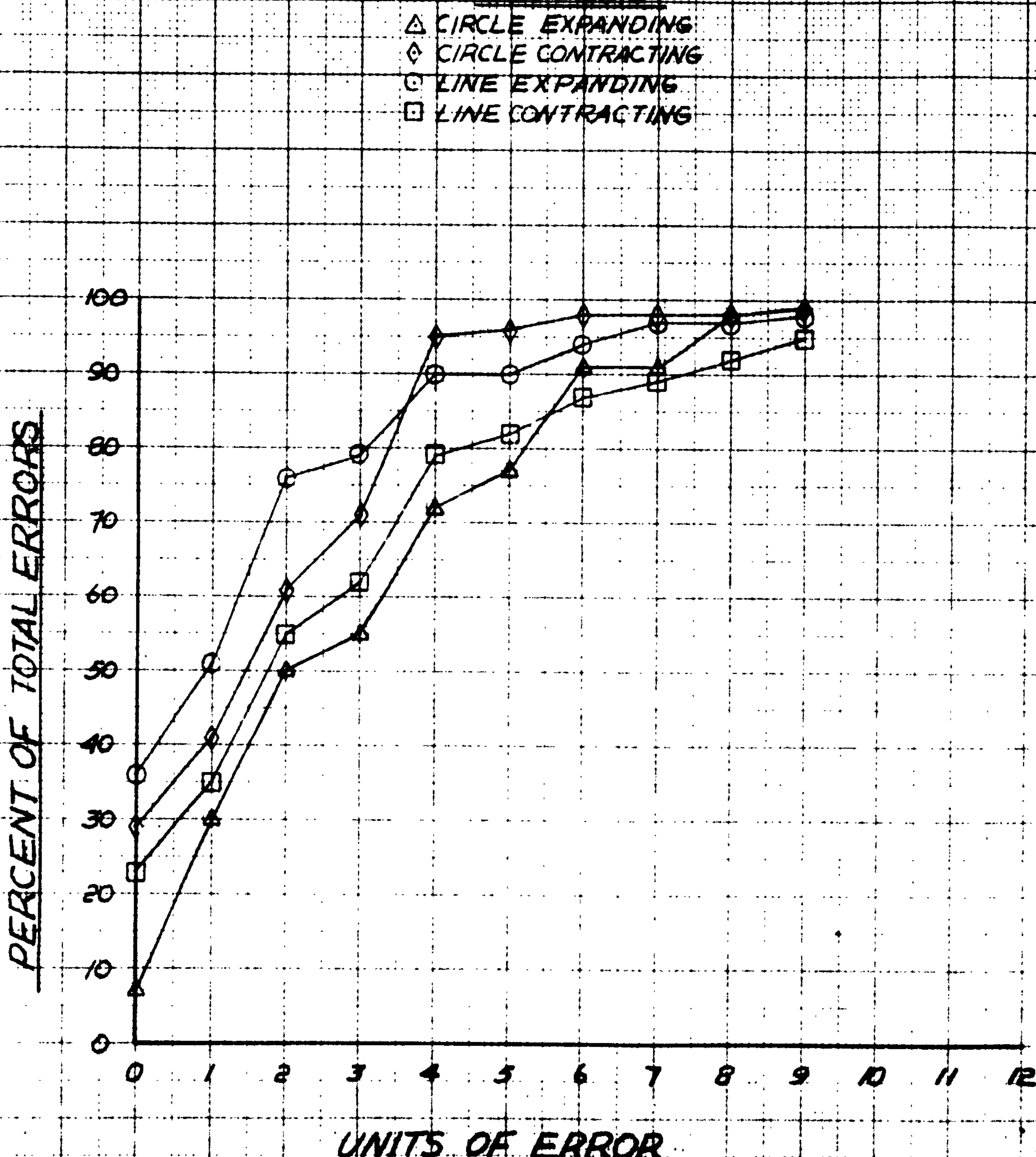
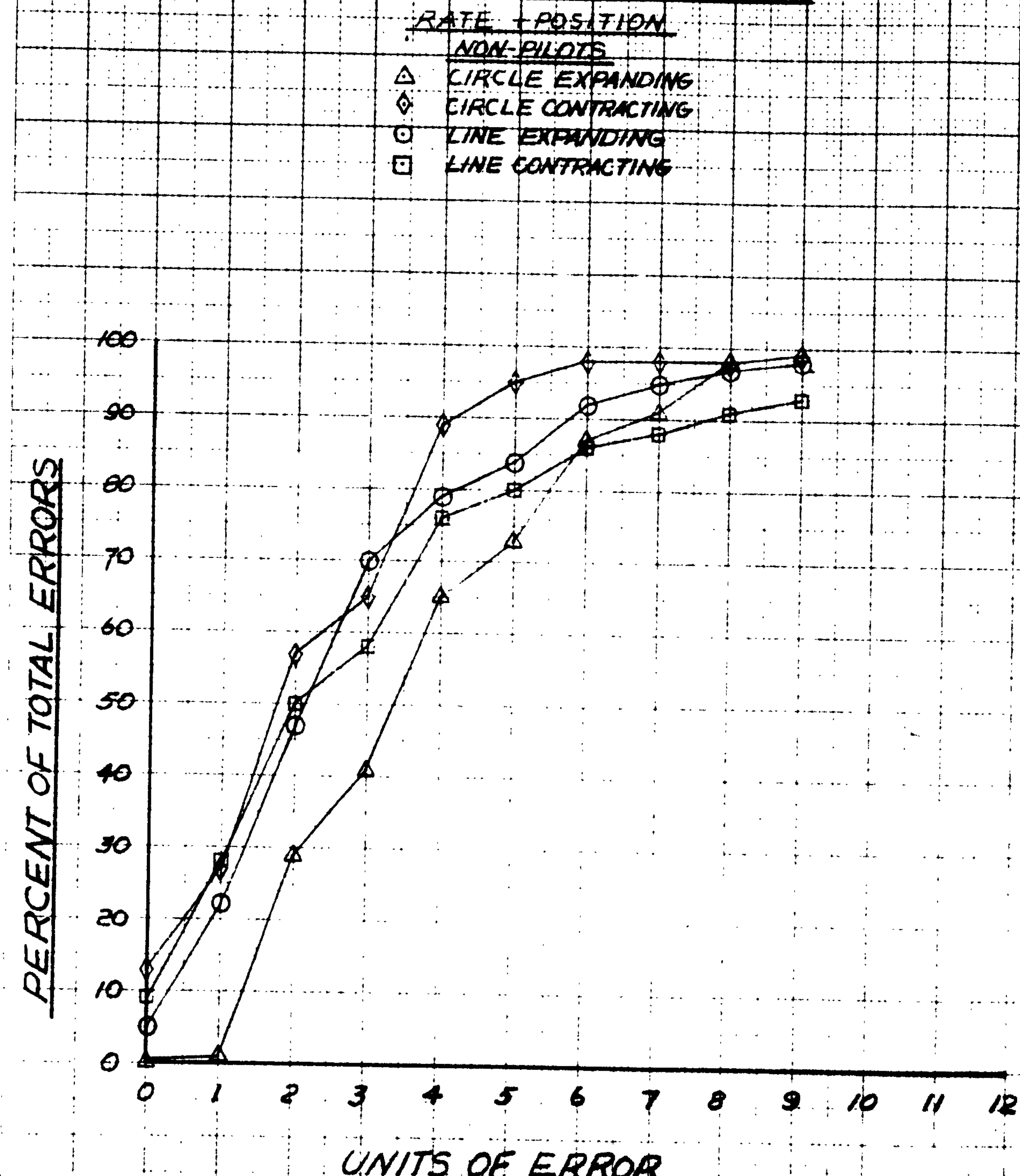


Figure 5
A DETERMINATION OF THE DISCRIMINATION & CONTROL OF RATE INFORMATION

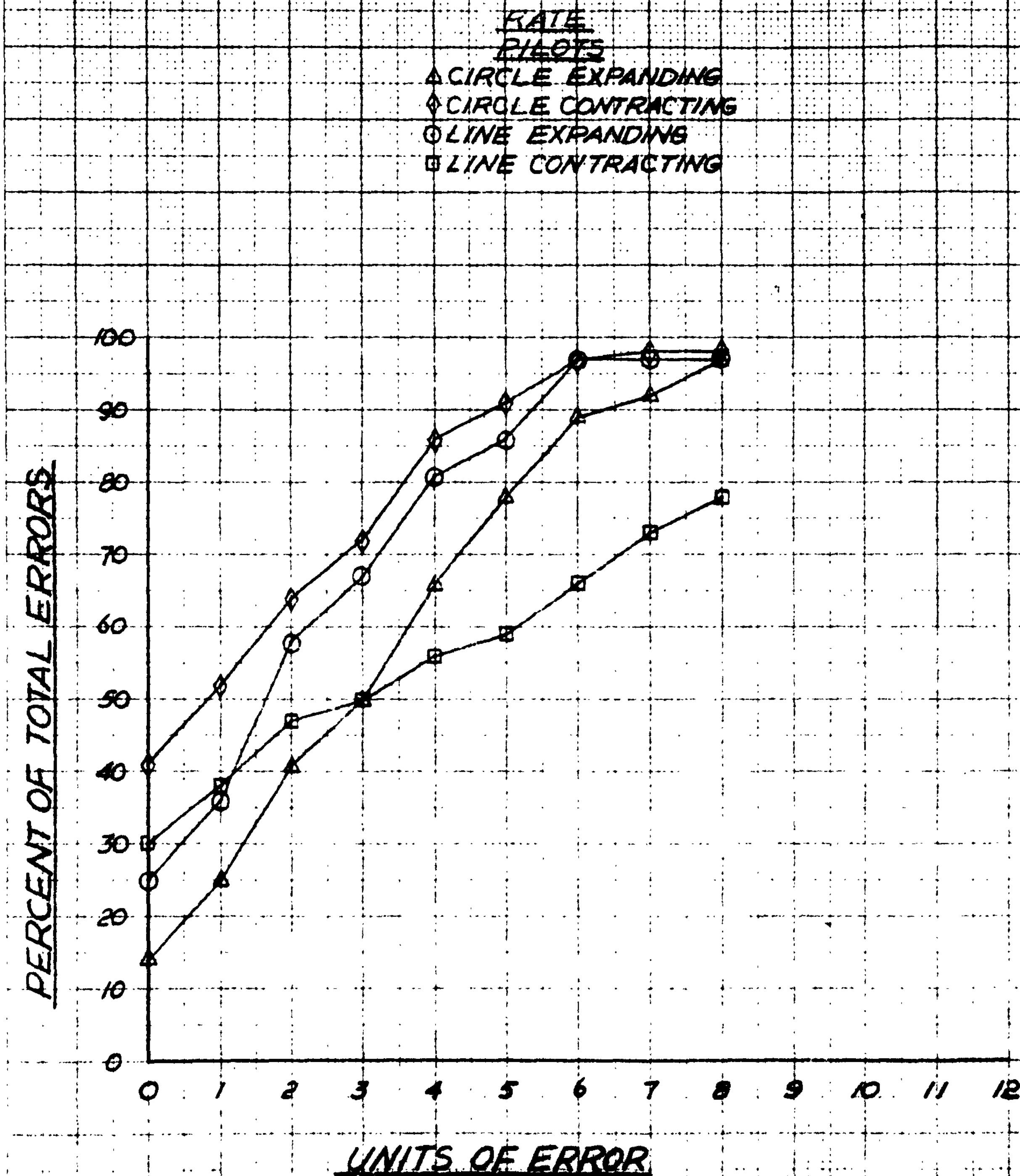



BAA 1-18-53

BY L. E. Wilkerson | CHECKED W. G. Matheny | BELL Helicopter CORPORATION | MODEL | BELL | PAGE 26 | REPORT D228-420-004

Figure 6

A DETERMINATION OF THE DISCRIMINATION & CONTROL OF RATE INFORMATION




BAA 4-18-60

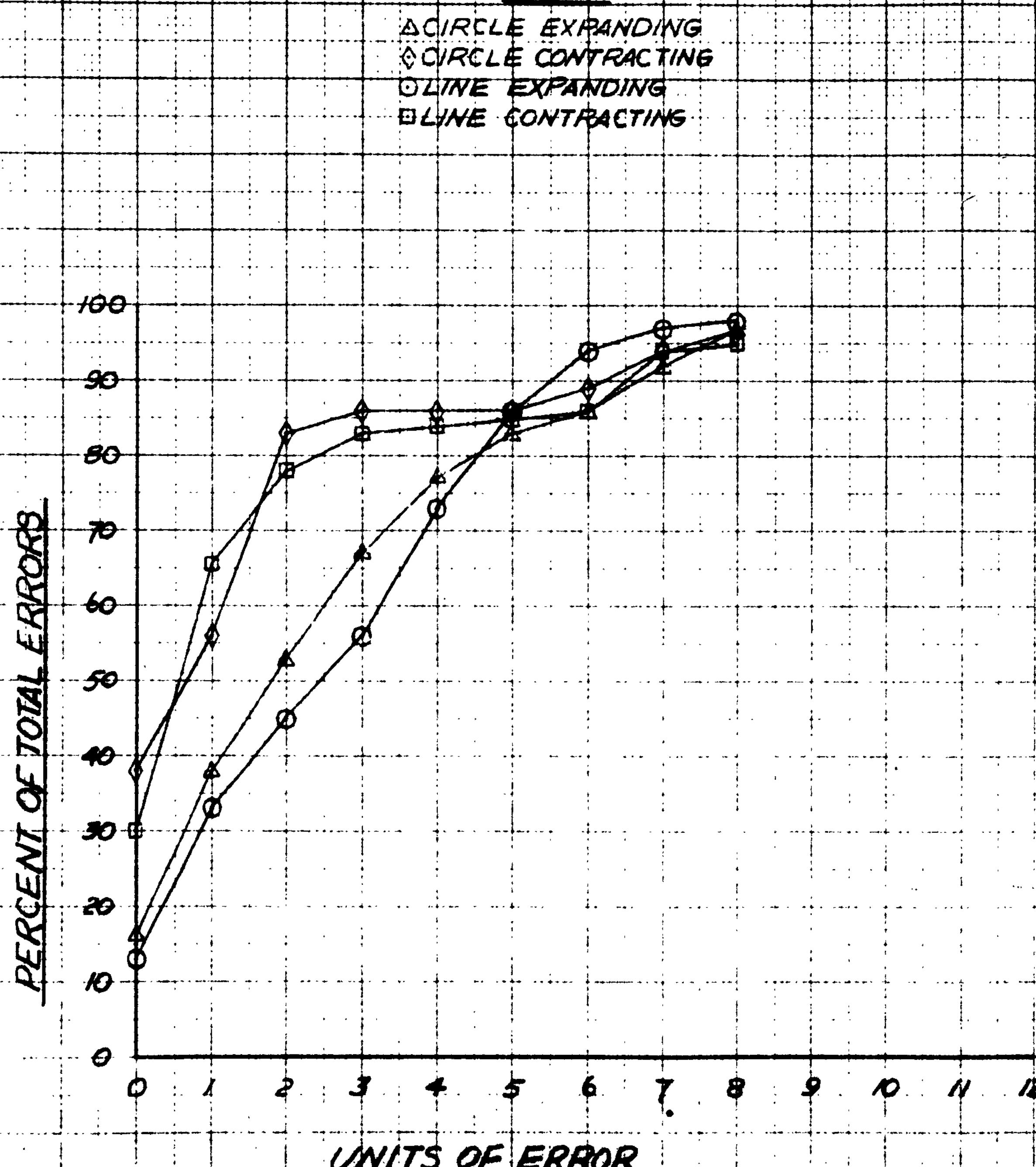
B4-000 FW Rev. 107

Figure 7

A DETERMINATION OF THE DISCRIMINATION & CONTROL OF RATE INFORMATION

POSITION

PILOTS



BY L. E. Wilkerson
CHECKED H. C. Hatberg

BELL Helicopter

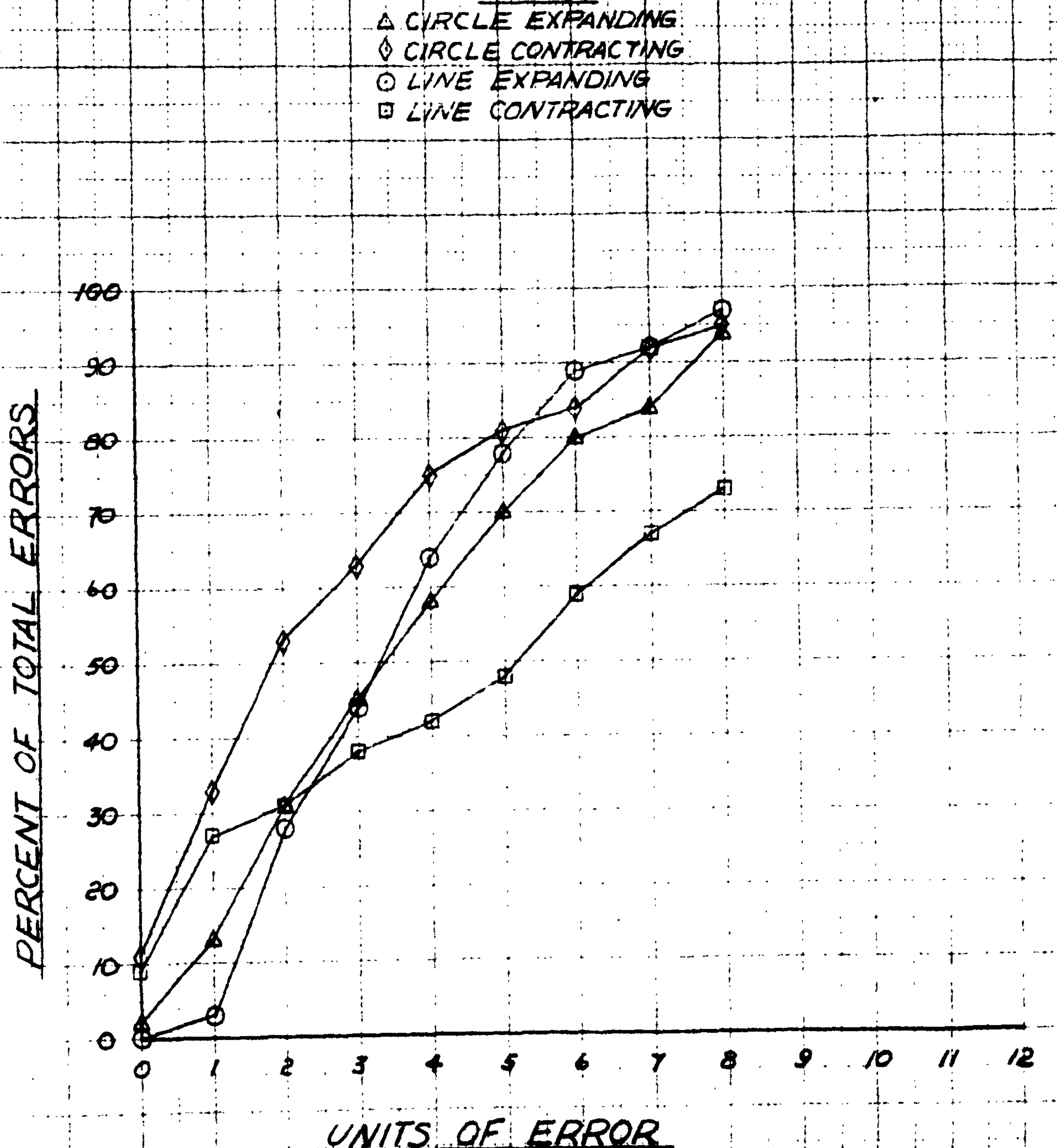
MODEL
BELL

PAGE 29
REPT D228-420-004

## Figure 8

## A DETERMINATION OF THE DISCRIMINATION & CONTROL OF RATE INFORMATION

RATE + POSITION
PILOTS




BAA
1-9-59

BY L. B. Wilkerson
CHECKED W. G. Matheny

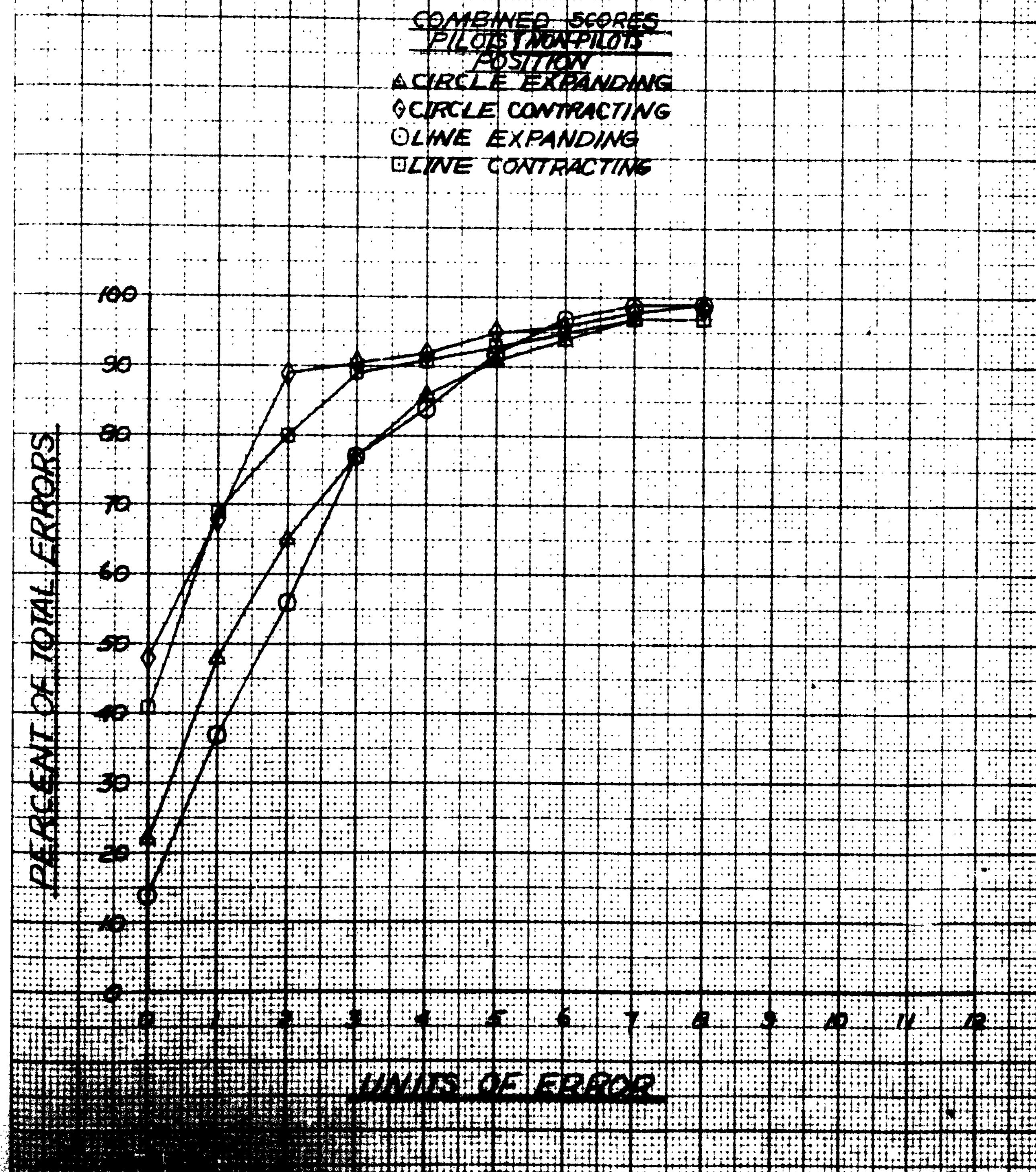
BELL Helicopter CORPORATION

MODEL
BELL

PAGE 29
RPT D228-420-004

Figure 9

A DETERMINATION OF THE DISCRIMINATION & CONTROL OF RATE INFORMATION



BY: L. B. Wilkerson
CHECKED: W. G. Matheny

BELL Helicopter Corporation

MODEL
BELL



Figure 10
A DETERMINATION OF THE DISCRIMINATION & CONTROL OF RATE INFORMATION

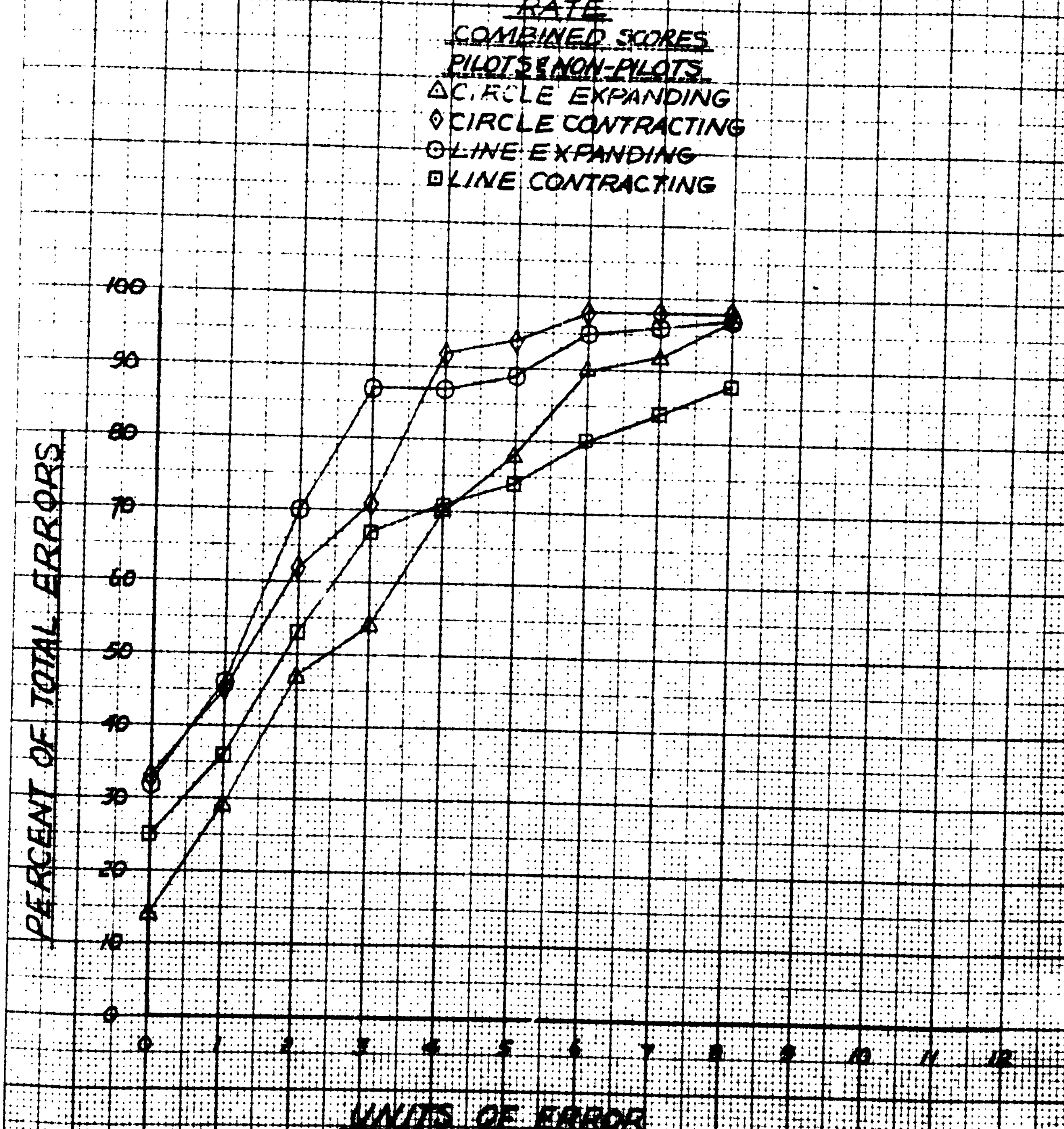
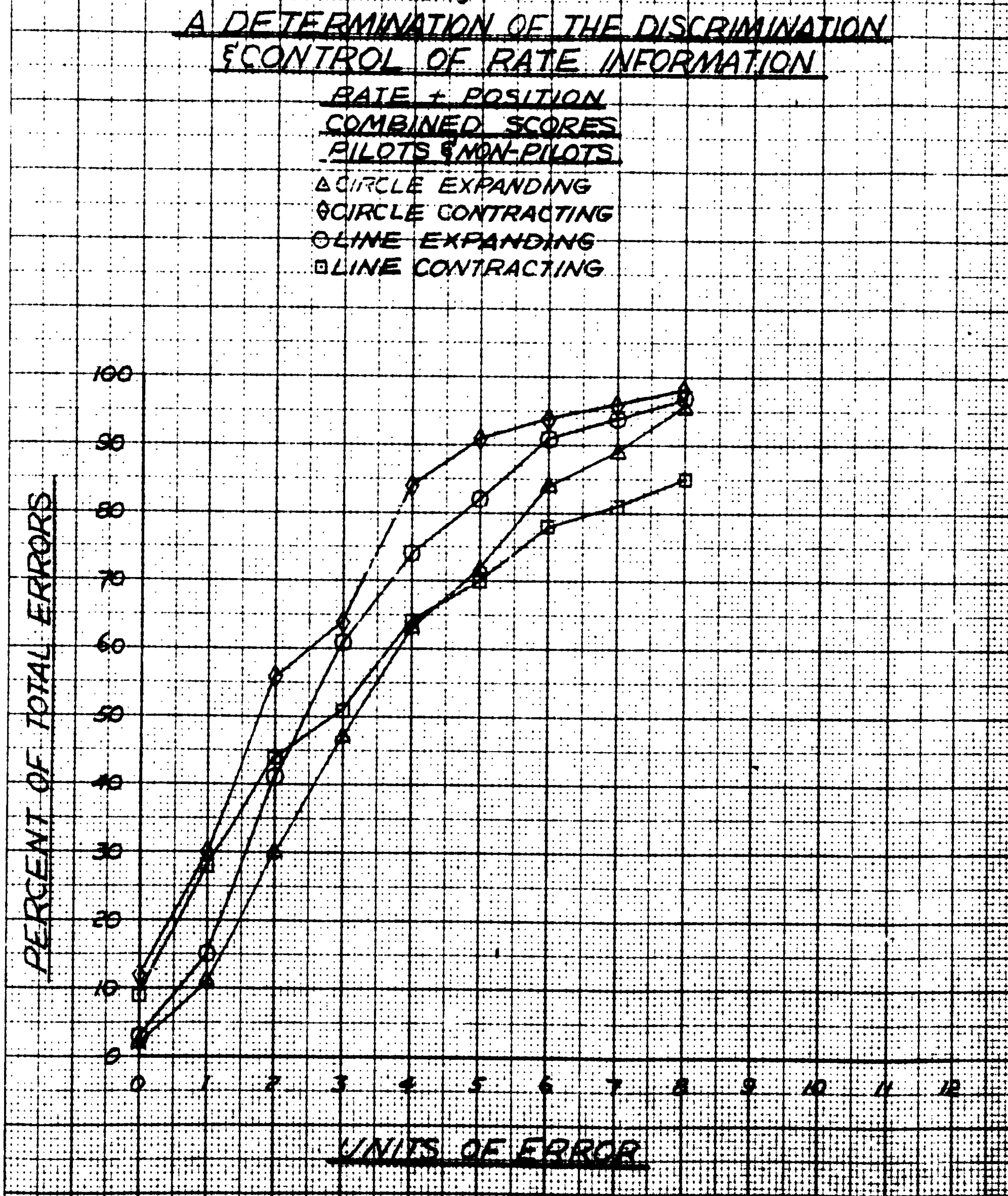


Figure 11



A DETERMINATION OF THE DISCRIMINATION & CONTROL OF RATE INFORMATION
RATE + POSITION
COMBINED SCORES
PILOTS & NON-PILOTS
△ CIRCLE EXPANDING
◇ CIRCLE CONTRACTING
○ LINE EXPANDING
□ LINE CONTRACTING
PERCENT OF TOTAL ERRORS
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
11
12
UNITS OF ERROR

## BIBLIOGRAPHY

1. Pellegrini, M. & Ponzo, M. "Individual and Interindividual variations in judging the speed of an automobile in motion." Arch. Ital. di Psical., 1928, 6, 115-24.

2. Dimmick, F.C. and Karl, J.C. "The effect of exposure time upon the RL of visible motion." J. Exp. Psychol. 1930, 13 365.

3. Zeger, R.T. "Monocular movement parallax threshold as a function of field size, field position, and stimulus movement." J. Psychol. 1948, 26, 477-98.

4. Adams, J.K., Ellson, D.G. and Gray, F.E. "A study of rate tracking by gunners on the B-29 pedestal sight." Report #6, OSRD #5638, 1945.

5. Wilson, Kellog V. "A distribution-free test of the analysis-of-variance hypothesis." Psychol. Bull., Vol. 53, No. 1, Jan. 1956.

6. Bell Helicopter Corporation Report 204-099-209.

# APPENDIX I

## INSTRUCTIONS TO SUBJECT

This experiment is designed to determine which of a series of visual presentations is the easiest to interpret. The different symbols will be presented on the scope before you. They will be a line and a circle. Sometimes they will start from the center and grow larger or longer, and sometimes they will begin at the outer edge and decrease in size. (Demonstrate)

You will be presented with four (4) different conditions and given eight (8) trials on each condition. You will start each trial when I say "now". The trial will be started by pushing the control on your right forward. Attain a rate of change at the target circle and try to maintain a constant rate of change until you hit the "change" point, then start a constant changing rate so as to reach a zero rate at the target circle without overshooting or undershooting. The farther you push the control the faster the line or circle increases or decreases. For each trial the amount of displacement of the control for a given rate will be changed at random. The trial will end when you have superimposed the line or circle on the target circle. When you judge that you have the moving symbol exactly on the target circle and stopped, press the switch and we will start a new trial. Remember that you will always start each trial by a forward movement of the control, whether the symbol is increasing or decreasing, and a trial will end when you have the target and symbol exactly coinciding and signify this decision by pressing the stop switch as soon as possible. Remember also to keep a constant rate of change to the "change" circle, then a constant decreasing rate to reach a zero rate at the target circle.

I will inform you at the start of each new condition. Do you have any questions? I will give you a short practice session so that you fully understand what you are to do. (PRESENT PRACTICE SESSION) Do you have any further questions? (After questions) We are ready to begin - ready, Now!

## DISTRIBUTION LIST

Office of Naval Research
Washington 25, D. C.
Attn: Code 461 ----------(2 copies)
Code 463 ----------(1 copy)
Code 466 ----------(1 copy)

Aeronautical Instrument Laboratory
Naval Air Development Center
Johnsville, Pa.
Attn: L. S. Guarino -(2 copies)

Bureau of Aeronautics (Code AV-430)
Washington 25, D. C. -(3 copies)

Office of the Chief Signal Officer
Dept. of the Army (SIGRD-5a)
Washington 25, D. C. -(2 copies)

Hq., Continental Army Command
Ft. Monroe, Va.
Attn: ATDEV-6 -(1 copy)

Office, Chief of Transportation
U. S. Army (ACofT (R&D)
Washington 25, D. C. -(1 copy)

Commanding General
U. S. Army Signal R&D Labs
Ft. Monmouth, N. J.
Attn: SIGFM/EL-SVN -(2 copies)

Army Electronic Proving Ground
Aviation Department
Ft. Huachuca, Arizona -(1 copy)

Deputy Chief of Staff Operations
Army Aviation Directorate
Washington 25, D. C. -(1 copy)

Army Aviation Board (M6 CONARC)
Ft. Rucker, Alabama -(1 copy)

Minneapolis-Honeywell Regulator Co.
Aeronautical Division
Minneapolis, Minnesota
Attn: Dr. John W. Senders -(1 copy)

Capt. Albert B. Crawford, Jr., SIG/C
Research & Tech. Operations Officer
Combat Development Dept.
U.S. Army Electronic Proving Ground
Ft. Huachuca, Arizona -(1 copy)

Chief, Engineering Electronics Section
National Bureau of Standards
Washington 25, D. C. -(1 copy)

Chief of Research & Development
Dept. of the Army (CSRD/D)
Washington 25, D. C. -(1 copy)

Commanding Officer
Transportation Research & Engr. Command
Ft. Eustis, Virginia
Attn: Aviation Division -(1 copy)

Commander
Hq., Air Research & Development Command
Attn: RDSTIL (Hq. Library Branch)
P. O. Box 1395
Baltimore 3, Md. -(1 copy)

Commandant
School of Aviation Medicine, USAF
Attn: Research Secretariat
Randolph AFB, Texas -(1 copy)

Documentation Incorporated
2521 Connecticut Ave., N.W.
Washington 8, D. C. -(1 copy)

Douglas Aircraft Company, Inc.
El Segundo Division
El Segundo, Calif.
Attn: Mr. Alfred M. Mayo -(1 copy)

Goodyear Aircraft Corporation
Akron 15, Ohio
Attn: Dr. A. J. Cacioppo -(1 copy)

Link Aviation, Inc.
Hillcrest, Binghamton, N.Y.
Attn: Mr. George B. Simon -(1 copy)

(Contd.)

DISTRIBUTION LIST -- (Contd.)

Dunlap and Associates, Inc.
429 Atlantic St.
Stamford, Conn.
Attn: Dr. Jesse Orlansky -(1 copy)

General Electric Company
Advanced Electronics Center
Cornell University
Ithaca, New York
Attn: Mr. Walter I. Carel -(1 copy)

Electric Boat Division
General Dynamics Corporation
Groton, Conn.
Attn: Dr. Albert E. Hickey -(1 copy)

Sikorsky Aircraft
South Avenue
Bridgeport, Conn.
Attn: Mr. Jack T. Stultz -(1 copy)